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APPLICATION OF THERMAL IMAGING CAMERAS FOR SMARTPHONE: SEEK THERMAL COMPACT PRO AND FLIR ONE PRO FOR HUMAN STRESS DETECTION – COMPARISON AND STUDY

Abstract

Thermography as an innovative diagnostic technique with non-contact temperature measurement is used in many industries – science, industry, medicine, and security. When using thermography in the field of health, images and images sequences obtained from thermal imaging cameras allow to record the temperature distribution in order to further recognize whether the state of the body is consistent with the defined parameters or whether there are deviations. However, it is worth paying attention to the measurement accuracy of thermal imaging cameras, their specification, and image quality of thermograms. In the case of recording stress states, measurement discrepancies between thermal imaging cameras for smartphone may affect the final results. Therefore, this article focuses on the comparison of the possibility of recording and detecting stress using two smartphone thermal imaging cameras: SEEK THERMAL Compact Pro and FLIR ONE Pro. The specifications of both cameras were compared. At the same time, the possibility of recording stress using smartphone thermal imaging cameras was confirmed on the basis of an exemplary study. The results of the comparison and analysis show that smartphone thermography can be a quick registration and diagnostic method in behavioral-biomedical issues.

1. INTRODUCTION

The first breakthrough thermographic experience – the discovery of infrared radiation by Sir Frederick William Herschel in 1800 (Ring, 2007; Campbell & Mead, 2022), contributed to the interest in developing the subject of thermography, also known as thermovision. The process of recording, processing and imaging infrared radiation, invisible to the naked eye and perceived as heat, has become the point of many researchers' interest (Panicker & Gayathri, 2019; Shanmugasundaram et al., 2019; Gedam & Paul, 2020). Receiving data, information about the temperature distribution on the surface of the tested object or a set of objects, allowed researchers to implement thermography in many areas, for example: industry, medicine, energy, military, mechanics, construction (Anusha et al., 2020; Kyriakou

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et al., 2019; Nath & Thapliyal, 2021; Pereira & Hallock, 2021). The most commonly used cameras are typically industrial cameras – stationary or portable. However, next to them there are still underrated smartphone thermal imaging cameras, which are often a low-cost measuring tool. Their great advantage is the possibility of intuitive use in any conditions, with full synchronization with smartphone. Researchers (Machado Fernández & Anishchenko, 2018; Anishchenko & Turetzkaya, 2020; Gomez de Mariscal et al., 2017; Meshram et al., 2020) appreciated smartphone thermal imaging cameras, using them even during complex medical events. The most often used in the research are cameras of the following brands: FLIR and SEEK. Although both brands provide quite good measurement possibilities, the existing measurement differences (resulting, for example, from the technical specification) may affect to the final results. So far, these cameras have been used in medical diagnosis (for example: fever, burn), while the author of this article used thermal imaging cameras for smartphone in own research on stress detection (Baran, 2021a; Baran 2021b). These articles discussed stress detection methods and tested the potential of the thermal imaging method, but did not focus on the thermal imaging cameras analysis with their measurement accuracy. Therefore, the author decided to compare smartphone thermal imaging cameras: FLIR ONE Pro and SEEK THERMAL Compact Pro on the example of recording and detecting stress states. At the same time, this comparison formed the basis for the selection of the main camera for further research carried out as part of the research project. There are no studies comparing cameras on the example of stress detection in the literature. There is only similar cameras comparison (the older FLIR ONE camera and the SEEK THERMAL Compact Pro camera) on the example of the use of thermal imaging cameras in biomedicine, and specifically for the toe damage analysis. However, this article does not include the considerations of measurement accuracy and thorough interpretation of the technical specifications (Kirimtat et al., 2020). The images comparison focuses on the temperatures visualization in the grayscale or pseudo-color thermal images of the feet. Thus, the entire work comes down to confirming the possibility of using thermal imaging cameras in diagnostics, without clearly indicating the leader among the analyzed cameras. With this in mind, the author of this article decided to go to a step further and check the detection capabilities of the latest FLIR and SEEK cameras in the psychological and biomedical field, more precisely – in stress detection field, taking into account a wider comparative range of cameras and accuracy factors of thermal imaging.

This article presents a comparison of thermal imaging cameras for smartphone: FLIR ONE Pro and SEEK THERMAL Compact Pro on the example of stress detection. Specifications and measurement accuracy of both cameras was included. A review of the works of researchers using smartphone thermal imaging cameras in various studies was presented. All the analyses confirmed the subject importance and the measurement capabilities of thermal imaging cameras for smartphone in the field of stress detection.

2. RELATED WORKS

The researchers' interest in the use of thermography in various areas of life can be seen in many thematic researches works. However, a smaller part of them are works where thermal imaging smartphone cameras are used. Most often, these cameras are used wherever a generally accessible, low-cost device is needed, for use in home or outside conditions.

Table 1 lists selected research approaches using thermal imaging smartphone cameras. Analyzing Table 1, it can be noticed that smartphone thermographic cameras have so far been used mainly in the medical field – in situations where abnormal temperature changes may indicate illness or damage to the analyzed human body part, for example: with burns. The obtained thermograms made it possible to assess the degree of disease, injury and to take appropriate action. Thus, thermography was a support and control tool at the same time.

Tab. 1. List of selected articles using mobile thermographic cameras

Article	Description	Comments
(Kanazawa et al., 2016)	Assessment of inflammation among people with pressure ulcers and a diabetic foot	Credibility: 95% FLIR ONE camera
(Qin et al., 2022)	Assessing the risk of diabetic foot ulceration	Smartphone thermography as a home health self-assessment tool
(Germi et al., 2022)	Monitoring changes in sympathetic function in patients undergoing anterior approach lumbar surgery	Using FLIR One camera with iPhone Help doctors track sympathetic function – easier and more accurately
(Passos & Da Rocha, 2022)	Assessment of smartphone thermography as a diagnostic tool in peripheral arterial disease of the lower extremities	Comparison of the possibilities of smartphone thermography and color Doppler ultrasonography
(Morales-Ivorra et al., 2022)	Remote assessment of patients with RZS relapses and assessment of disease activity	Multicenter observational studies using cameras: FLIR One Pro or Thermal Expert TE-Q1
(Moran-Romero & López-Mendoza, 2022)	Postoperative monitoring of free flaps	Three case reports of ambiguous thermal imaging results Understanding of the limitations and capabilities of smartphone thermal imaging
(Nassar et al., 2022)	Comparison of modalities utilized for preoperative planning in microsurgical reconstructive surgery	Comparison: CT Angiography, MR angiography, conventional angiography, dynamic infrared thermography and other
(Bogomilsky et al., 2022)	Preliminary study of thermal density distribution and entropy analysis during cycling exercise stress test	Tests on the SRM stationary ergometer Use of FLIR One and MATLAB
(Luze et al., 2022)	Mastectomy skin flaps assessment for intermediate reconstruction with implants	Preoperative screening for risk factors and intraoperative skin-perfusion assessment via FLIR One
(Ahn et al., 2022)	Evaluation of knee arthritis with joint effusion	Comparing two methods: thermal imaging with power Doppler (PD)
(Hallock, 2019)	Identification of preferred perforators or hot spots of the vascular network in operations to ensure perfusion of the perforator flap	Quick identification
(Theuma & Gassar, 2018)	Examination of acute lower limb ischemia	Thermal imaging as a support for diagnosis and treatments in the operating room
(Xue et al., 2018)	Assessment of 3rd degree burns thanks to ICG angiography and thermal imaging	Using FLIR ONE Designation of incurable tissues (areas)
Cho et al., 2017a)	Breathing tracking (inhalation and exhalation cycles)	Introduction of the Thermal Voxel method to capture respiratory signals

Thermography and smartphone thermal imaging camera can also be used in stress detection, which the author confirmed in the works (Baran, 2021a). Researchers who detect stress through thermal imaging most often use advanced industrial thermal imaging cameras, for example: FLIR Boson, Tau640. In addition, they often combine thermal imaging with signal recording devices, for example: ECG, EEG, GSR (then thermal imaging is usually of secondary importance). Selected works by researchers who use various thermal imaging cameras (both industrial and smartphone ones) to detect stress are presented in Table 2.

Tab. 2. List of selected articles using thermographic industrial cameras

Article	Description	Camera	Classification
(Cardone et al., 2020)	Stress analysis while driving a car	FLIR Boson 320LW, Intel RealSense D415	SVR z RBF Kernel, ROC analysis Accuracy: 77%
(Cho et al., 2017b)	*DeepBreath* stress detection system	FLIR ONE, spectrogram	CNN Accuracy: 84.59% for a binary classification and 56.52% for a 3-class classification
(Kaga & Kato, 2019)	Stress load testing with simultaneous ECG and NIRS measurement – near infrared spectroscopy, NST – nose skin temperature	FLIR, EKG, OEG-Sp2 spectogram	Random forest, step method (STEP) – feature extraction and signal selection, SVM – stress estimation Accuracy: 76.5%
(Bara et al., 2020)	Study of multimodal interactions between the presence of stress and the manifestation of affect	FLIR A40, MuSE base	RNN, CAs (Convolutional Autoencoders)
(Liu et al., 2020a)	Detection of physical stress by hyperspectral imaging of facial tissue saturation with oxygen (StO2) in five areas of the face	FLIR SC7600, HSI system	Logistic Regression, Linear Discriminant Analysis, kNN, Decision Tree, Team Learning, SVM Accuracy: 82.11%
(Akbar et al., 2019)	Measuring stress and the interaction between stress and emails triggering it	Tau640 thermal camera, HD Pro C920 webcam	GLM model
(Sharma et al., 2013)	The use of the thermal (TS) and visible (VS) spectrum and the ANU StressDB database	FLIR thermal camera, Microsoft webcam	Pattern matching algorithm, HDTP (dynamic thermal pattern capture) method proposal, SVM Accuracy: 72%

It its worth emphasizing that stress may manifest itself as a change in one of the various psychological signals of a human, like: blood volume pressure, temperature, respiratory volume, ECG, EEG, EMG, GSR. The above-mentioned signals are the most common research foundations of stress reactions in the work of most researchers. At the same time, the measurement of stress is often accompanied by questionnaires, for example: *Ardell Wellness Stress Test, Perceived Stress Scale, Standard Stress Scale, Stress Coping Resources Inventory* (Panicker & Gayathri, 2019; Baran, 2021b). Classification algorithms are also used in stress detection – the most common are: SVM, kNN, fuzzy logic, random forest (Liu et al., 2020b; Rodríguez-Arce et al., 2020; Sharma et al., 2021). Stress can be caused by external factors (like fear, emergency, watching a stressful movie) or internal factors (like hot bath, pregnancy, inflammation). In the situation of inducing stress in the laboratory, the following are used: affective images, movies, music, texts or arithmetic mental tasks (Baran, 2021a).

3. COMPARISON OF THERMAL IMAGING CAMERAS FOR SMARTPHONE

The market for thermographic cameras is quite large, however, thermal imaging cameras for industrial, construction or electronic applications dominate mainly. Thermal imaging smartphone cameras are not that popular, but they still find interest. The main models of thermal imaging smartphone cameras belong to the brands FLIR System (a pioneer and leader among manufacturers of thermal imaging cameras) and SEEK. The other versions of smartphone cameras are often low-cost “noname” cameras.

The latest IR cameras are most often equipped with thermal detectors (uncooled) or photon detectors (cooled). Uncooled detectors can be: bolometric, microbolometric, mosaic, pyroelectric, semiconductor, and photon detectors – photoconductive, photovoltaic. For military or scientific purposes, mainly IR cameras with cooled detectors are used, and cameras with uncooled detectors – for construction, transport and firefighting applications. For example, FLIR cameras (3rd generation) use thermal detectors together with FPA – *Focal Plane Array*.

The purchase of a thermal imaging camera should correlate with the needs of use, awareness of technical specifications and measurement accuracy. If the user is interested in high detail of the measurement, he should get to know the technical parameters, test camera models with dedicated software, and then make a choice. In smartphone thermal imaging cameras, compatibility with smartphones is very important – unfortunately, some cameras can only work with selected smartphone models or the operating system.

In the following sections, smartphone thermal imaging cameras will be compared: FLIR ONE Pro and SEEK THERMAL Compact Pro – both on the basis of technical specifications, measurement accuracy and in terms of stress detection possibilities.

3.1. Technical specifications

Table 3 lists the technical specifications of smartphone thermal imaging cameras: SEEK THERMAL Compact Pro and FLIR ONE Pro. Both cameras – shown in Fig. 1 – are among the most popular and available cameras on the market. They can be classified as low-budget cameras that work with the majority of the most popular smartphones. As shown in Fig. 1, the cameras are compact – the FLIR ONE Pro is much larger than the SEEK THERMAL Compact Pro, and also has an HD visible light camera and thermal imaging system. Also, the weight of the FLIR ONE Pro (36.5g) is much higher than that of the SEEK camera (14g).

Considering the cameras size and weight, the SEEK camera seems to be more compact device. The cameras connection with a smartphone is most often done via a micro-USB and USB-C type, depending on the version purchased. It is worth adding that FLIR camera has an adjustable OneFitTM connector that allows to set the connector in the range of 4mm, so that the camera can be adapted to the smartphone placed in the case (eliminating the need to remove the smartphone form the case when using camera).

Fig. 1.Views of thermal imaging smartphone cameras: FLIR ONE Pro (left) and SEEK THERMAL Compact Pro (right)

Taking into account the issues of ecology and environmental friendliness, it is worth paying attention to the materials from which the cameras are made. Certainly, the material should provide resistance to falls, guarantee product durability and resistance to electromagnetic radiation. In the case of the SEEK THERMAL Compact Pro, the material looks like cheap, hard plastic of medium quality. The FLIR ONE Pro is made of synthetic resin, so the camera has a soft casing (important as shock absorption in the event of a fall). Unfortunately, this camera does not have a cover that can protect the lens from scratching or breaking. The lens material in both cameras is the same – they are vulcanized synthetic materials. The best material for lenses is definitely germanium – transmittance > 95%. In the case of synthetic materials (based on selenium sulphide or zinc sulphide) the permeability is about 90% and with a total coating it is about 95%. The higher the material's transmittance, the clearer and cleaner the image of the lens can be. Thus, the accuracy of the temperature measurement will be increased.

Tab. 3. Table title (source) (font size: 9, bold)

Criteria	**SEEK THERMAL Compact Pro**	**FLIR ONE Pro**
Thermal Resolution	320 x 240 pixels	160 x 120 pixels
Temperature Range	-40°F to 626°F (-40°C to 330°C)	4°F to 752°F (-20°C to 400°C)
Thermal Sensitivity	70 mK	150 mK
Thermal Accuracy	N/A	±3°C or ±5%
Frame Rate	15 Hz	8.7Hz
Field of view	32°	55° x 43°
Detector types	Thermal detector	Thermal and photon detectors
Internal Battery	No, uses smartphone battery	Yes, 1h life
Built-in Digital Camera	No, uses smartphone digital camera	Yes, 1440 x 1080 resolution
Focal Type	Fixed-focus	Fixed-focus
Emission factor	glossy 50%, matt 97%, semi-gloss 60%, semi-matt 80%	glossy 30%, matt 95%, semi-gloss 60%, semi-matt 80%
Smartphone app	SEEK THERMAL	FLIR ONE
Reporting software	No	Yes, FLIR Tools
Image Technology	No	Yes, FLIR MSX
Focusing	Auto, Manual Focus Ring	Auto Focus only
Safe class	Weather resistance	Drop resistance form 1.8m
Measurement type	Qualitative	Quantitative and qualitative

When analyzing the technical specifics of both cameras from Table 3, it can be seen that the temperature measurement range is wider for the FLIR ONE Pro camera. However, for everyday use (for example: controlling the temperature of water for washing babies, bodies of domestic pets), the temperature ranges of both analyzed cameras are more than enough – in everyday life, hardly anyone has contact with temperature above 100°C, and both cameras offer measurements up to 330°C. FLIR ONE Pro offers also up to 400°C. When it comes to measuring accuracy, for FLIR ONE Pro it is indicated as ±3°C or ±5%. According to SEEK Support, the measurement accuracy of SEEK THERMAL Compact Pro is at a similar or lower level than that of the FLIR ONE Pro camera. Temperature measurement with both cameras is very fast, but its accuracy should be controlled, for example: by using a non-contact thermometer, using camera calibration.

The noticeable difference between the two cameras is the aspect of image blending or overlay technology. FLIR developed the MSX technology (Multispectral Dynamic Imaging) and applied it to the FLIR ONE Pro camera, thanks to which the MSX imposes visual details (edges of the examined object) from the visible band to the thermal image (the FLIR camera is equipped with a thermal imaging system and an HD visible light camera). As a result, the thermal image is clear, sharper, with visible details and of increased quality. The FLIR ONE Pro has the ability to align the edges of the infrared image and the visible image. Higher accuracy of temperature measurements is also ensured by the unique processing technology VividIR™, which allows to generate images with 4-times more pixels, which translates into the accuracy of the measurement. There is no image assist technology in the SEEK THERMAL Compact Pro.

Very seemingly, the SEEK camera wins when it comes to IR resolution – 320 x 240 pixels, which provides four times more pixels and higher quality of thermal images compared to the 160 x 120 pixels of the FLIR camera. However, as indicated earlier, FLIR has MSX and VividIR technologies that ensure the detail and clarity of IR images (visualization of object outlines in a thermal image in real time), and thus – compensate for the resolution. In addition, FLIR has an HD detector allowing a resolution of 1024 x 768px (which gives ~0,8Mpx compared to ~0,02MPx at 120 x 160px). The more pixels there are, the more detailed the infrared image is and the more likely it is to get an accurate measurement. FLIR ONE Pro has a worse thermal sensitivity – 150mK, where for SEEK it is 70mK. The lower the thermal sensitivity value of the so-called NETD (Noise Equivalent Temperature Difference), the better the accuracy for narrower temperature ranges. Unfortunately, the greater the NETD value, the greater amount of noise. For body temperature measurements, a thermal sensitivity of < 60 mK is recommended, because the range of interest is narrow, usually 36-40°C. In the case of focal length, both analyzed cameras have a fixed focal length type. The Focal View (FOV) parameter is related to the focal length, which informs what the visible area in the camera will be in the vertical and horizontal planes. FOV value for the FLIR camera: 55° x 43° means that the camera has a field of view of 55° horizontally and 43° vertically, which may indicate a focal length of approx. 44mm. SEEK camera has FOV 32°.

Comparing also the refresh rate Hz, we can notice that the FLIR camera has a higher value – 15Hz (SEEK – 8.7Hz). The higher value of FPS, the less noticeable the delay effect of the image produced by the thermal image camera relative to the actual scene. The emissivity coefficients for individual materials are comparable in both cameras. The choice of emissivity depends on what measurement will be performed, however, for skin temperature testing, an emissivity of 0.98 is recommended.

FLIR ONE Pro, despite the registration advantage, loses to SEEK THERMAL Compact Pro in terms of batteries. The FLIR camera has a lithium-ion battery that needs to be charged before use (charging time – approximately 1 hour). The battery life is very short – about 30 minutes, max. 1 hour. The time is shortened more when the ambient temperature is lower. For conducting research with a FLIR camera, short battery life can be a limiting factor. In addition, some users of this camera report high failure rate and problems with charging the battery even after a short time of not using the camera. For example: the camera has not been used for 3 days, the green LED flashes when recharging, but the camera fails to turn on. It is different with the operation of the SEEK camera – it is powered by a smartphone via a USB connection, so that the operation of the camera depends on the phone's battery (there may be excessive battery consumption). SEEK users rarely report problems with the operation of this camera. The lack of an internal battery in the SEEK camera also means smaller dimensions and weight of the camera.

Another point of comparison is the applications and software for cameras. Both cameras work with dedicated smartphone applications. It is worth checking the requirements of applications and cameras for a smartphone. Unfortunately, some smartphones may not work with the analyzed cameras, so it is worth reading the manufacturer's indications. The Seek Thermal and FLIR One applications have similar functions. They offer, among others: the possibility of choosing a color palette, changing the temperature unit, selecting the recording mode, viewing photos or thermal recordings. As for the software, FLIR offers free reporting software – FLIR Tools. This software allows to import radiometric infrared images, make corrections, create reports and send them directly from the program. SEEK does not have such software.

The recording mode of thermal images for both cameras is similar. The FLIR camera has the following modes: MP4 videos, JPEG photos, time-lapse videos. In the FLIR ONE app settings, can save thermograms to smartphone's image library. In the SEEK camera, the format of the saved files is also JPEG and MP4.

The manufacturers of both analyzed cameras provided protection to their devices – FLIR declares resistance to a fall from a height of 1.8m, while SEEK – resistance to weather conditions, as well as resistance to falls. In addition, SEEK indicated the observation range up to 500m, while for FLIR it is indicated that the focus can be adjusted in the range from 0.3m to infinity.

Image quality issues of both cameras are discussed in next subsection on the basis of exemplary thermal images obtained.

Based on the preliminary analysis and the list in Table 3, it can be initially stated that the FLIR ONE Pro camera looks better in terms of its capabilities. The parameters of the SEEK THERMAL Compact Pro camera are very good, but the FLIR brand has an advantage in the field of assistive technologies, which ultimately ensure higher registration quality. For further comparison, it is also important to check the measurement accuracy of both analyzed cameras in order to check the quality and accuracy of thermal imaging.

3.2. Measurement accuracy

Modern industrial thermographic cameras ensure high measurement accuracy. They should not be compared with smartphone equivalents, because smartphone thermal imaging cameras often have a different scope of application, budget and work factors, including cooperation with a smartphone. Smartphone thermal imaging cameras are to be an intuitive and handy tool for a basic user, for home and field use. Both cameras measurement accuracy should be visible through the detail of the thermal photo/recording and the correctness of the object/objects temperature measurement. Various factors will affect the measurement accuracy of both cameras. One of the basic factors is the issue of setting the camera parameters. The main ones are the emissivity settings. Both cameras have several setting options, for example: Sub Light, Semi Matte, Semi Highlight, Highlight. An experienced camera user should have no problem setting the emissivity value for a given material, and thus – obtaining correct, accurate measurement results. This can be problematic for new users and beginners (need to understand the emissivity phenomenon). Another important factor in measuring accuracy is the detector resolution and sensitivity. The higher the infrared resolution and detector sensitivity, the more detailed the infrared image is, and therefore the more accurate the results. It is also worth taking into account the measuring environment. Due to their specificity of operation, thermal imaging cameras can be used in various places, but their effectiveness may be reduced in case of high air humidity, fog, snow, rain (suppression of infrared waves). By equalizing the temperature of the object with the ambient temperature, the camera loses the resolving power. The ambient temperature is required to compensate for the radiation reflected from the object. Correct setting of the ambient temperature is of great importance, especially when the emissivity of the object is low. The emissivity can range from 0 to 1, depending on the material of the object. The larger the errors in the thermal imaging measurement, the greater the difference between the temperature of the measured object and the ambient temperature, and the lower the emissivity. Lower accuracy and errors in thermovision measurements may also result from incorrect reflection of sunlight from the tested surface, as well as disturbing factors from the environment. Manufacturers of thermal imaging cameras suggest that cameras operating in the long-wave range (8-14μm) should be used in open areas. It is worth paying attention to weather conditions – stronger wind may cool the tested object by up to a dozen or several dozen degrees °C. The following may also affect the measurement results and even apparent temperature differences:

- observation angle (depending on it, the emissivity coefficient changes),
- shape of the tested object (specific shapes such as waviness, roughness may generate discrepancies in the measurement results),
- reflectance (reflectance and emissivity complement each other),
- changes in emissivity (affecting the apparent real temperature difference),
- radiation transmittance (the appearance of apparent temperature differences when radiation is emitted by objects behind the tested object),
- mass movement (moving masses transporting heat and causing thermal anomalies – air drafts, winds),
- heat capacity (heat storage, objects heating, and thus the impact on the temperature variation over time),

- induced heat (inducing currents or fields, temperature changes in the field area),
- energy conversion (heat influencing the increase of the surface temperature of the tested object),
- direct heat transfer (temperature increases due to phenomena, for example: friction, thermal reactions).

During laboratory tests or at home, thermal imaging cameras meet requirements such as: appropriate room temperature (preferably 20-21°C), emissivity value 0.98, adjusted distance of the camera from the examined person (depending on the optics), air humidity in the room not greater than 50%, proper camera calibration, proper camera location (avoiding additional flashes, radiation), proper configuration of settings. All this is aimed at minimizing the measurement error and ensuring effective measurement.

In the literature review presented in earlier section, it can be seen that despite technical differences, thermal imaging cameras are used in various areas. Moreover, it does not prevent advanced research and classification of disease entities. Thermal imaging smartphone cameras can certainly perform a diagnostic, control or supporting role.

4. RECORDING AND DETECTING STRESS WITH THERMAL IMAGING CAMERAS FOR SMARTPHONE - COMPARISON

A stress detection test was conducted to check the measurement accuracy of the FLIR ONE Pro and SEEK THERMAL Compact Pro cameras. The cameras use the same palette – the rainbow – in the temperature range of 20-38°C (from dark blue to white). Also, the measurement parameters, such as correction, reflection, distance, emissivity, were the same for both cameras. Temperature unit was °C. For accurate measurements, the calibration of the camera was checked and the temperature was controled using a MesMed MM-331 handheld thermometer. The study involved 20 people who were recorded with both cameras simultaneously while watching a stressful short film. The age range of the participants was 19-32 years (10 men, 10 women). The participants were without any disabilities. They agreed to participate in the study by signed research documents. Before starting the study, participants were relaxed by listening to relaxing music or having fun conversations. During the recording, not only the temperature on the participants' faces was recorded, but also their pressure and pulse were measured. After the examination, the participants were asked to complete the PSS-10 psychological test determining the level of perceived stress. The data from the research was obtained as a result of processing in OpenCV (analysis of red areas with the highest dynamics of change). Measurement accuracy is taken into account in the calculations for reliable results. During the research session, appropriate working conditions for thermal imaging cameras were ensured – the cameras and their configuration were calibrated, the temperature in the test room was 21°C, without air drafts and additional light sources. Pressure and pulse were measured with the S-Fit 18 smartband (in real time, with ±2% accuracy). All research sessions (recording thermal videos) were conducted in accordance with the research procedure adopted in the research project "*Application of thermal imaging for stress detection*".

5. RESULTS

The processed thermal recordings from both cameras allowed to obtain the final data on the basis of which the following were generated, among others: the graph shown in Fig. 2, data in Table 4. The graph shows how stress increased while watching a stressful video (stress accumulation at the end of movie) – recording with FLIR ONE Pro camera (author shows graph for better detection results camera). Table 4 presents the percentage occupancy of the areas with the highest dynamics of temperature changes (areas in the red color range) in relation to the entire thermal image in selected frames of thermal recordings (the peaks of dynamic changes). Correlating Table 4 with Fig. 2, the graph shows the input value at the start, the output value at the end of the recording, as well as peaks: 1-3 between the seconds: 29-34 (time of stress climax and sudden thermal change on the face). This allows to confirm the occurrence of sudden stress arousal and then an attempt to return to a normal state (without stress).

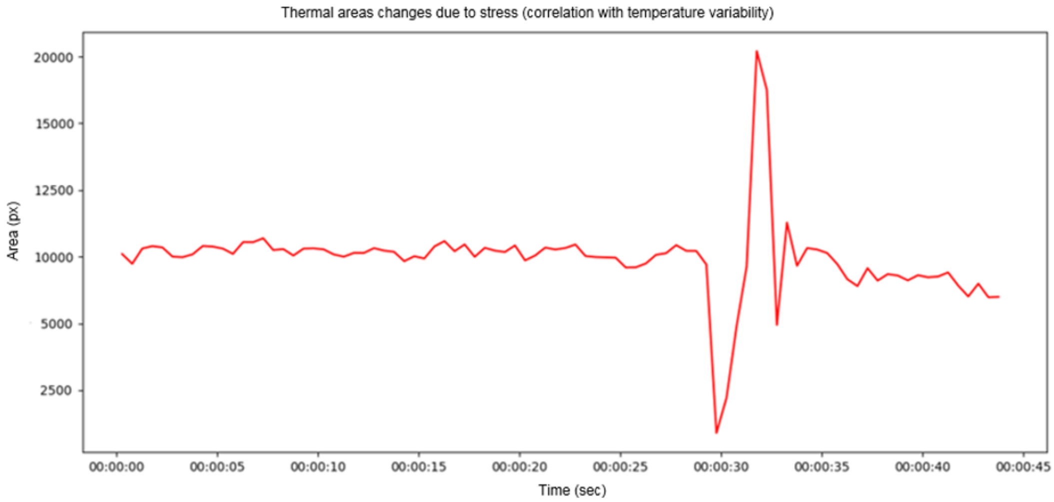

Fig. 2. A graph showing the change in the size of thermal areas and the stress response during the study (recording with the FLIR ONE Pro camera – better results than with SEEK Compact Pro)

Tab. 4. Comparison of the % of red areas value (the greatest dynamics of changes) in thermal recordings with camera: SEEK THERMAL Compact Pro and FLIR ONE Pro

Camera	**% of the red area value of the entire image**				
	Input	**Peak 1**	**Peak 2**	**Peak 3**	**Output**
SEEK THERMAL Compact Pro	53,75	4,78	69,01	25,57	37,35
FLIR ONE Pro	56,77	5,29	83,33	30,27	41,54

Fig. 3 and Fig. 4 summarize selected thermal frames from both cameras of exemplary participants (input frame and two example frames with the biggest stress reaction). This compilation allows noticing changes in the blood supply to the face along with the increasing intensity of the stressful situation in the film watched by the participants (especially frames:

2-3 in both figures). Comparing input frame with second and third frames, it was noted that thermal and color changes corelate with stress reaction.

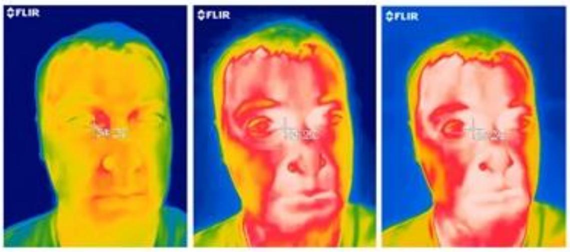

Fig. 3. Summary of thermal images from the FLIR ONE Pro (selected participant)

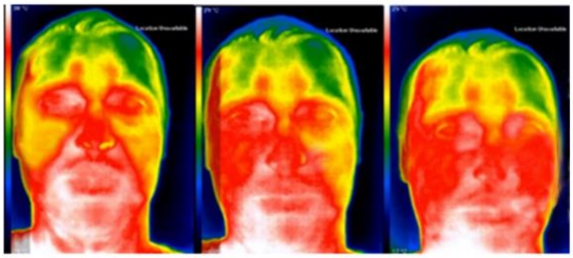

Fig. 4. Summary of thermal images from the SEEK THERMAL Compact Pro (selected participant)

Tab. 5. Summary of the physiological measurements and the results of the psychological test for group

Participants	Pressure		Pulse		PSS-10	
	Relax	Stress	Relax	Stress	Result	Sten
1	103/75	110/79	75	99	26	8
2	117/86	119/83	84	96	25	8
3	121/82	123/87	95	89	20	7
4	112/79	110/72	84	79	24	8
5	105/69	110/74	70	74	23	8
6	119/80	117/82	72	72	12	4
7	120/79	125/86	86	98	25	8
8	107/86	109/88	74	81	20	7
9	119/74	119/80	73	77	21	7
10	103/62	104/83	77	87	26	8
11	128/88	131/90	101	107	18	6
12	124/75	127/86	86	93	17	6
13	115/82	119/79	98	98	17	6
14	111/89	113/86	93	99	16	5
15	123/84	124/68	93	95	25	8
16	118/78	120/79	84	84	10	4
17	120/82	122/84	77	69	21	7
18	120/79	124/78	96	97	20	7
19	109/86	111/81	94	96	26	8
20	117/77	120/72	72	87	21	7

Table 5 presents the obtained results of physiological measurements and the results for the PSS-10 test. It is worth adding that the measurements of pressure and pulse were carried out using a smart band, and the averaged values in the table refer to the state of relaxation and stress. For the PSS-10 test, the values are relevant: Results and Sten. The PSS-10 consists of 10 questions, which are assigned a score from a 5-point likert scale: from "never" to "always". The summed up points give a score, which is then assigned to the stens. Sten norms allow to interpret point scores. It is assumed that stens of 1-4 mean low values, 5-6 average, 7-10 high. Therefore, PSS-10 is used in stress monitoring and prophylactics, as well as in effectiveness control of therapeutic activities.

6. DISCUSSIONS

By analyzing Fig. 3 and Fig. 4, it can be stated that both compared cameras provide high registration quality. Although the resolution of the FLIR ONE Pro is 160 x 120, the image quality is comparable or even better than the image quality of the SEEK THERMAL Compact Pro with a resolution of 320 x 240 (due to the previously mentioned HD detector in the FLIR camera). The SEEK camera sees only the main target (hotspots), while the rest of the elements are less clear or almost invisible. Images from the FLIR camera are clearer, showing the outlines of objects (edges) – thanks to the use of MSX technology. Similar technology works in the SEEK camera but only in the SeekShot series. Table 4 confirms that the FLIR One Pro better captured the changes in the areas with the highest temperature dynamics (areas in the red). The change of the leader takes place when recording or thermal photos from a greater distance (several meters) – the image in SEEK THERMAL Compact Pro shows details more than the image from FLIR ONE Pro, where it is more difficult to distinguish objects. The field of view, focal length and thermal sensitivity discussed earlier are responsible for this. In the case of stress detection tests, the camera is placed close to the face of the subject in order to capture the most accurate image. So in this case, the FLIR ONE Pro camera performs better, as it guarantees better image quality at a closer recording distance.

In the case of the graph in Fig. 2 and data from Table 4, it can be seen that the registration accuracy is at a similar level with an advantage for the FLIR ONE Pro camera. Both cameras registered changes in the blood supply to the face manifested in changes in temperature. On the basis of both charts, it can be indicated that the plot line is consistent with the intensity of the stress action occurring in the film. Stress culminates in the final part of the film, which is manifested in the chart by sudden jumps in values, followed by an attempt to return to the initial value. Table 5 presents the results of the measurements of pressure and pulse of the participants along with the results of the PSS-10 psychological test. Based on Table 5, it can be concluded that the results confirm that the participants were put in a stressful situation that influenced them to a varying degree. Analyzing the respondents individually, it can be concluded that those of low level of stress experienced a smaller range of changes in facial temperature, while those who were sensitive showed greater susceptibility to a stressful situation. The results from the PSS-10 test indicate a subjective level of perceiving stress during the last month. As shown in Table 5, the group of participants was dominated by people with a high stress index (sten scale: 7-10, marked in red), people with an average result were four (sten 5-6, marked in blue), and the sten score was low, in the 1-4 range, only two people (marked in green). On this basis, it can be concluded that most of the group during the study period had increased symptoms of stress (main causes: excess work, new pandemic regulations, armed conflict in a neighboring country).

Taking into account the technical specifications of both cameras and the presented image comparisons along with the stress test, it can be concluded that the FLIR ONE Pro camera guarantees better quality of recordings, images than SEEK THERMAL Compact Pro. Its biggest disadvantage is the issue of a short-lived battery. In terms of appearance, weight or size, the SEEK THERMAL Compact Pro camera certainly looks better, which also ensures quite good image quality. The SEEK camera has advantages on several points of specification, the main one being IR resolution – 320 x 240 pixels, providing four times the pixels and higher quality of thermal images compared to the 160 x 120 pixels of FLIR camera. But as mentioned earlier, FLIR compensates for this with MSX technology, which ensures the detail and clarity of IR images (making the outlines of objects visible in the thermal image in real time). By comparing the views of the thermal images shown in Fig. 3 and Fig. 4, a greater detail in the imaging of the FLIR ONE Pro camera can be seen.

7. CONCLUSIONS

Although smartphone thermal imaging cameras have been operating on the electronic equipment market for several years, they are still an underrated measuring tool. The work of the researchers presented in the article confirms that smartphone thermal imaging cameras are used even in advanced and complex medical issues. Their low-cost and intuitive operation make it possible to use them not only in laboratory conditions, but also at home.

Smartphone thermal imaging cameras analyzed in this article provide a high level of measurement accuracy. According to the analysis of both cameras, in terms of technical specifications, the FLIR ONE Pro camera looks better, with its clever technology and dual detector guaranteeing better thermal imaging quality. The example of stress detection shows the differences in imaging, the main one being visible, for example, in the detail of the image. FLIR brings out the details, making the image clearer. The SEEK camera, despite its lower measurement accuracy, also deserves to be appreciated. It can certainly be used in the field of stress detection. However, wanting more accurate measurement results, it is recommended to use the FLIR ONE Pro camera. Comparing the obtained results with the results of the work of other authors, especially it can be noted that in this article not only the correctness of thermal imaging stress detection was confirmed, but above all two smartphone cameras were thoroughly analyzed, which allowed to indicate the leader. And this was missing from the work (Kirimtat et al., 2020). In this article thermal images were analysed, technical specifications were interpreted and measurement accuracy was considered. The whole gives a broader view of the recording of stress with smartphone thermal imaging cameras.

FLIR ONE Pro and SEEK THERMAL Compact Pro as smartphone thermal imaging cameras provide photos, high-resolution thermal images. These cameras are certainly much cheaper thermal imaging tools than standard industrial thermal cameras. Thermal images and recordings obtained with IR cameras enable the interpretation of thermal patterns and point out anomalies. Higher infrared resolution guarantees detailed and easy to interpret infrared images.

The study of stress detection using smartphone thermal imaging cameras confirmed their suitability for psychological and medical applications. The method of thermal stress detection can be an option for quick and accurate control, analysis or diagnosis. The use of smartphone thermal imaging cameras in psychological and medical aspects will certainly be developed by the author during further thematic research also related to AI, planned in the future.

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Conflicts of Interest

None.

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